backscattering RF with continuous zero bits. One hundred microseconds after completion of the Polling message, the transponder shall begin transmitting its message.

Section 1705.5. Transponder Communications Protocol.

(a) *Subcarrier Modulation Scheme* .
The transponder-to-reader (uplink) modulation scheme shall be amplitude modulation of an RF carrier backscatter created by varying the reflecting crossection of the antenna as seen by the incident carrier signal. The antenna crossection shall be varied between upper and lower limits with a 50 percent duty cycle and rise and fall times of less than 75 nanoseconds.The transponder baseband message signal shall modulate the subcarrier using FSK modulation with a center frequency of 900 kHz and frequency deviation of ± 300 kHz. The lower and upper subcarrier frequencies correspond to data bits '0' and '1' respectively. The message information is conveyed by the subcarrier modulation frequencies of the transponder backscattered signal and not by amplitude or phase.

(b) *Data Bit Rates.*
The data bit rate for transponder-to-reader data messages shall be 300 kbps.

(c) *Field Strength.*
The field strength at which a transponder data message is transmitted using backscatter technology is dependent upon the incident field strength from the reader, the transponder receive and transmit antenna gains, and any RF gain internal to the transponder. The transponder and antenna gain taken together shall effect a change in the backscattering cross section of between 45 and 100 square centimeters.

(d) *Standard Transponder Data Message Format.*
The standard portion of a Transponder data message shall consist of a header and transaction record type code. The subsequent length, data content, and error detection scheme shall then be established by the definition for that transaction record type.

(e) *Transponder Data Message Formats For AVI Toll Collection.*
There may be numerous transponder-to-reader data message formats. The format is determined by the Transaction Record Type code sent by the transponder. The following is the transponder-to-reader message format presently specified for AVI electronic toll collection applications:

(1) ***Transponder Transaction Type 1 Data Message.***
Transponder Transaction Type 1 Data Message allows for unencrypted transponder ID numbers to be transmitted. Type 1 data messages shall be structured using the following ordered data bit fields:

Field Definition	No. Bits	Hexadecimal Value
Header		
Selsyn	8	AA
Flag	4	C
Transaction Record Type Code	16	1
Transponder ID Number	32	

Error Detection Code		16
	Total:	76

(f) *Transponder End-of-Message Frame*
The End-of-Message signal for transponder data messages shall consist of a minimum of 10 microseconds of no modulation.

Section 1705.6. Transponder Response to Reader Acknowledge Message.

The Transponder shall discontinue responding to identical reader polling requests for a period of 10 seconds once a valid reader acknowledgement message has been received. The transponder shall, however, respond to polling messages that are not identical to the polling message that lead to the valid acknowledgement.

Section 1705.7. Multiple Transponder Responses to a Reader Polling Message.

Each transponder data message transmittal must be in response to a reader polling message.

Section 1705.8. Transponder Positioning.

Transponders shall be positioned at the front of the vehicle with a clear line of sight to the reader antenna without degrading the performance of the reader-transponder system below minimum specified standards. As a minimum, transponders shall operate up to a maximum of 76cm (30") offset from the longitudinal center line of the vehicle.

The front of the vehicle shall be defined as that portion of the vehicle from the driver's eyes forward.

Attachment 2 to Appendix L

VRC Reader-Transponder RF Protocol Specification (May 15, 1995)

HTMS

SPECIFICATION

Title: VRC Reader-Transponder RF Protocol Specification

DCN: VRC_P_001

Revision: 1.2

Release Date: May 15, 1995

Equipment: Protocol

Project:

Approvals

Originator:	**Program/ Product Development Manager:**
Technical Director:	**Product Support Manager:**

1 Scope

This standard defines the protocol and radio system for dedicated short-range, half-duplex, active, two-way vehicle-to-roadside communications (VRC) equipment.

This standard is intended to meet the requirements for many of the VRC applications defined by the Intelligent Transportation Society of America for Commercial Vehicle Operations (CVO), Advanced Traveller Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Electronic Toll and Traffic Management Systems (ETTM), Advanced Public Transportation Systems (APTS), and Advanced Transportation Management Systems (ATMS).

This standard defines a means to guarantee accurate and valid message delivery, between moving vehicles entering a communications zone and a fixed roadway infrastructure, for both wide-area (multi-lane, open road) and lane-based applications.

The wide-area protocol permits transactions with several vehicles travelling on a multiple lane roadway without restricting the vehicle to any fixed lane, trajectory or speed. The applications may be characterized by the capability to perform general two-way digital communications with multiple vehicles simultaneously in an open road operating environment, with minimal implementation restrictions. The protocol allows interoperability to occur by transmitting other protocol signals during assigned TDMA communication timeslots.

The lane-based protocol permits a transaction with a single vehicle travelling on a restricted trajectory. The applications may be characterized by the capability to exchange a short duration, fixed length message with a single vehicle when it passes through a specific location on the roadway. The lane-based protocol is defined to be a subset of the wide area protocol, and permits interoperability with other existing dedicated short range vehicle communications standards described herein. The protocol allows interoperability to occur by transmitting other protocol signals during assigned TDMA communication times.

The VRC equipment is composed of two principal components: a Beacon and a Transponder. The Transponder is intended for, but not restricted to, installation in or on a motor vehicle. The Beacon (also referred to as the Reader) controls the protocol, schedules the activation of the Transponder, reads from or writes to the Transponder, and assures message delivery and validity. It is intended for, but not restricted to, installation at a fixed location on the roadway. Application specific interoperability with other existing dedicated short range communication standards shall be a function of beacon equipment.

The beacon and antenna equipment must be capable of receiving and decoding data messages from closely spaced transponders in the same lane and/or adjacent lanes. This standard defines a system which shall communicate and perform reliable message transactions between the beacon and any transponder at speeds up to 200 kph (~125 mph), and at spacing between transponders as low as 0.5 meter. Degradation of performance below the specified levels shall not take place within the above speed and spacing requirements.

This standard is not restricted to operation in the United States only.

A summary of operational characteristics is given in Table 1.

PARAMETER	OPERATIONAL CHARACTERISTICS
Carrier Frequency	Country/Application Specific (subject to assignment)
Carrier Modulation	Unipolar ASK (Manchester Encoded)
Data Bit Rate	500 kbps
Message Data	512 data bits per TDMA packet, single or multi-packet transactions
Technology Type	Two-way Active RF
Antenna Location	Application Specific
Protocol	TDMA/Adaptive Slotted Aloha Access

Table 1 - Summary of Operational Characteristics

2 Referenced Documents

The following documents are referenced in this specification and form a part of this specification to the extent refernced herein:

- ANSI Specification C95.1 (current revision)

3 Terminology

3.1 Acronyms and Abbreviations

Following is a definition list of acronyms, abbreviations and miscellaneous technical terms used in this specification:

- ACK - Acknowledgement
- *AM* - Amplitude Modulation
- *ASK* - Amplitude Shift Keying
- *AVI* - Automatic Vehicle Identification
- *Carrier Frequency* - A location in the Electromagnetic Spectrum allocated for VRC system services
- *CRC* - Cyclic Redundancy Check
- *Downlink* - Communications from a Beacon to a Transponder
- *ERP* - Effective Radiated Power (ERP = peak antenna gain x transmit power)

- *EM* - Electromagnetic
- *FCC* - Federal Communications Commission
- *FCM* - Frame Control Message
- *HELP* - Heavy Vehicle Electronic License Plate
- *ID* - Device Identification
- *kbps* - kilobits per second
- *kHz* - kilohertz (10^3 hertz)
- *kph* - kilometers per hour
- *MHz* - megahertz
- *RAM* - Random Access Memory
- *RF* - Radio Frequency
- *Uplink* - Communications from a Transponder to a Beacon
- *VRC* - Vehicle to Roadside Communications

3.2 Communication Layer Terms

The following sections define communication layer terms used in this specification.

3.2.1 Beacon

A fixed position controller, also referred to as a *Reader*, associated transmit and receive (Tx/Rx) antenna(s), and modulation and demodulation hardware and software. Communication with existing dedicated short range AVI transponders shall require dual mode operation in the beacon.

3.2.2 Byte Order

Numeric fields shall be transmitted most significant bit first. If a numeric field is represented by multiple bytes, the most significant bit of the most significant byte shall be transmitted first. This document represents the most significant, and first transmitted, to the left on a line and to the top of a multi-line tabulation.

3.2.3 CRC

This field is defined as a Cyclic Redundancy Check. Error detection must be performed each time a data message is sent so that the receiving party can ascertain the validity of the data stream. The specified form of the cyclic redundancy check is the CRC-16, with generator polynomial of $x^{16} + x^{15} + x^2 + 1$. This results in a16-bit value transmitted with each data message. The data packet protected by the CRC excludes any preceding header in every case.

3.2.4 Data Packet

The message information, excluding the Header, communicated between the transponder and beacon. Multiple packets may be transferred in each frame, and in multiple frames.

3.2.5 Frame

A cyclic structure consisting of the Message Control Phase, the Transaction Phase with one or four message slots, and the Activation Phase using Slotted ALOHA link access techniques.

3.2.6 Header Code

The Header defines the start of each message and consists of an 8-bit self-synchronization pattern (Selsyn) and an 8-bit start-of-message flag for a total of 16 bits. The Selsyn pattern has binary value of 01010101. The start-of-message flag has binary value of 10001101.

3.2.7 Link Validation

A 7-bit linear sequence generator shall be used to perform link validation. The generator shall be a 7 stage shift register with polynomial $x^7 + x + 1$. Only messages transmitted in the message slots (within the Transaction Phase) shall be validated. All data fields except the Header and CRC shall be included in the validation process. The beacon shall pick a random 64-bit Validation Seed each frame and transmit it in the Frame Control Message. This seed shall be used, along with the message data, by the message source (transponder or beacon) to generate a Validation Check byte. This value shall be calculated for each Slot Data Message transmitted in the frame. The Validation Seed shall be used to initialize the sequence generator by clocking it through the generator. The sequence generator shall be re-initialized by the Validation Seed for each Slot Data Message transmitted in the frame. During reception, data is then clocked through the sequence generator. Following the data, eight additional zeroes are clocked. The output of the sequence generator for these eight bits is the Link Validation Check byte. This is compared to the check byte in the received message to determine validity.

3.2.7.1 Link Validation Check Byte

An 8-bit field generated by the validation algorithm, and appended to the transmission to validate a received Slot Data Message.

3.2.7.2 Link Validation Seed

A 64-bit random or pseudo-random number which initializes the validation algorithm for all message transactions in a given frame. This feature provides uplink playback protection for the beacon.

3.2.8 Slot Command

A field which defines the type of transmission or reception that the transponder will perform during the transaction phase.

3.2.9 Transponder

An electronic device attached to a vehicle and containing information that can be communicated with the beacon.

3.2.10 Transponder ID Number

The code or serial number that uniquely identifies a transponder.

4 Physical Layer Radio Frequency Characteristics

4.1 RF Carrier Frequency

The VRC system shall operate at an RF carrier frequency which permits a bandwidth sufficient to maintain system signal reliability. Specific frequency and bandwidth shall be dependent upon local telecommunications assignment for each country and attached to this standard as separate addenda.

4.2 AM Modulation Scheme

The modulation scheme shall be unipolar amplitude shift keying (ASK) of the RF carrier using Manchester encoding as shown in Figure 4-1. A data bit '1' is transmitted by sending an RF pulse during the first half of the bit period and no signal during the second half. A '0' data bit is transmitted as no signal during the first half of the bit period and an RF pulse transmission during the second half.

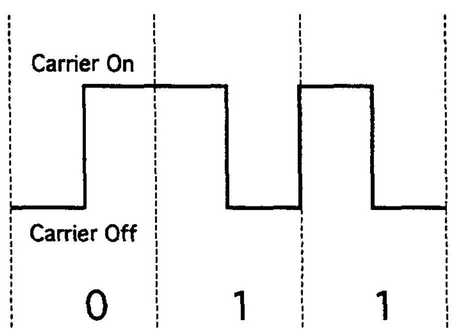

Figure 4-1: Manchester AM ASK Coding Example

4.3 Bandwidth

The data bit rate for all messages shall be 500 Kbps (kilobits per second). This data rate implies a minimum transponder receiver bandwidth of approximately 1.5 MHz.

4.4 RF Carrier On/Off Ratio

The ratio of power output in the "on-burst" to the power output in the "off-burst" shall be greater than 20 dB.

4.5 Transponder Characteristics

4.5.1 Antenna Location

The transponder shall establish a communication link with a beacon located at any point in the hemisphere in front of the transponder antenna. Transponders shall meet the performance specified herein when positioned in the front window, or, if suitably packaged, on the front bumper or license plate.

Transponder may be mounted separately from its antenna for specific applications.

Alternative mounting positions, for use on specific applications, shall maintain a clear line of sight to the beacon antenna.

4.5.2 Antenna Polarization

RF transmissions shall be horizontally polarized. Operational characteristics shall be tested when transmitting in an anechoic environment using a horizontally polarized test antenna.

4.5.3 Antenna Beamwidth

3 dB beamwidth shall be 100° minimum in elevation and 70° minimum in azimuth.

4.5.4 Transponder Activation

A transponder shall initiate activation in less than 20 milliseconds after entering the beacon communication zone. This zone is defined by the area in which the received field strength exceeds the specified transponder threshold.

4.6 Beacon Characteristics

4.6.1 Antenna Polarizations

The beacon transmit and receive antennas shall have predominant electromagnetic (EM) field components. Horizontal linear, vertical linear, circular or elliptical polarizations are allowed. Polarization is application specific.

4.6.2 Antenna Location

For lane-based and wide area operation the beacon antenna location is site specific.

4.6.3 Field Strength

The beacon shall transmit at RF power levels allowed at the operating frequency for each country, region, and/or application.

5 Data Link Layer

5.1 General Protocol

The beacon shall control all transactions with transponders, and implement a slotted ALOHA, time division multiple access (s-TDMA) data link control protocol as defined below. The protocol is based on a cyclic structure, known as a frame, as shown in Figure 5-1. Frames are transmitted continuously and contiguously. The frame consists of a Message Control Phase (with the Frame Control Message), a Transaction Phase (with data message slots), and an Activation Phase (with activation slots). The protocol permits multiple transponders to simultaneously request permission to perform a transaction. The beacon then commands up to four transponders to communicate in one or more specific message slots within the frame. At the conclusion of each transaction, a confirmation mechanism is used. If the transaction fails for any reason, a mechanism to repeat the transaction is initiated.

5.2 Selectable Frame Structure

The VRC protocol implements a dual frame structure to optimize performance for both wide area (open-road) and lane-based applications.

5.2.1 Wide Area Frame

There shall be four message slots and sixteen activation slots.

5.2.2 Lane-Based Frame

There shall be one message slot and four activation slots.

5.3 Message Control Phase

The frame structure, synchronization, message slot assignments, transaction type, and data link control shall be commanded by the beacon during this phase via the Frame Control Message (FCM). Assignments are based upon requests received during Activation Phases of preceding frames. The beacon may assign multiple message slots and/or multiple frames to a transaction with a transponder. In this case, the slot command and Transponder ID will appear in multiple slot assignment fields in the FCM.

5.4 Transaction Phase

The slot command in the FCM shall indicate the type of transaction and in which slot(s) the transaction shall be performed. A transaction may be transmit or receive, addressed or broadcast, and internal or external data messages.

5.4.1 Message Acknowledgement

The beacon shall send an acknowledgment message after each scheduled addressed transponder transmission. The transponder shall send an acknowledgment message after each scheduled addressed transponder reception. The acknowledgment shall be set positive if a valid message is received (i.e., no CRC error and no link validation error). Otherwise, the acknowledgment shall be set negative. An incorrectly received acknowledgement shall be considered negative.

5.5 Activation Phase

The Beacon shall transmit a FCM at the beginning of each frame to define the frame structure, enable activation, and establish synchronization with transponders. Transponders successfully decoding the FCM shall randomly choose an Activation Slot and prepare to send a Transponder ID message. The beacon shall listen for Transponder ID Messages in all of the activation slots at the end of the current frame, and shall make appropriate transaction assignments in the next available frame. A sample activation and link entry sequence is shown in Figure 5-2.

5.6 Frame Timing

Frame timing is illustrated in Figure 5-1 and summarized below.

5.6.1 Frame Timing Accuracy

Unless otherwise noted, the frame timing accuracy shall be ± 450 ppm (parts per million) for all transponder transmissions and shall be ± 100 ppm for all Beacon transmissions.

5.6.2 Guard Bands

Guard Bands, defined as a time period of no RF transmission, shall be as follows:

Following each FCM	100 µsec

Following each Activation Phase	250 µsec +10%,-0%
Following each Transponder ID Msg	8 µsec
Following each Transponder-Originated SDM	40 µsec
Following each Reader-Originated SDM	100 µsec

5.6.3 Extended Header

An extended header, consisting of one of the following data patterns– all binary "1's", all "0's", or alternating 1's and 0's– shall be transmited prior to the messages specified below. The preferred data pattern is "0101....". The number of bits of extended header shall be as follows:

Prior to the FCM	375 bits
Prior to each Reader-Originated Acknowledgement Msg	30 bits
Prior to each Reader-Originated SDM	30 bits

5.7 Message Formats and Field Sequencing

5.7.1 Frame Control Message

The Frame Control Message (FCM) provides link control, frame parameters, and dictates the transaction assignments that are to be performed by transponders in the current frame. The length of the FCM is 272 bits. A summary of the fields within the FCM is given in Table 2 below.

FIELD DEFINITION	NO. BITS	BINARY VALUE
Header Code:		
Selsyn	8	01010101
Flag	8	10001101
Frame Control	4	-
Message Type	4	1100
Slot 1:		
Command	8	-
Transponder ID	32	-
Slot 2:		
Command	8	-
Transponder ID	32	-
Slot 3:		
Command	8	-
Transponder ID	32	-
Slot 4:		
Command	8	-
Transponder ID	32	-
Sleep Timeout	4	-

Spare	2	00
Activation Response Parameter	2	-
Validation Seed	64	-
CRC	16	

Table 2 - Frame Control Message Structure

5.7.2 Slot Data Message

The Slot Data Message (SDM) contains a data packet to or from the transponder. The content of the Data Message is application-specific. Unused bits shall be set to zero. The length of the SDM is 560 bits. A summary of the fields within the SDM is given in Table 3 below.

FIELD DEFINITION	NO. BITS	BINARY VALUE
Header Code: Selsyn Flag	 8 8	 01010101 10001101
Data Link Header	4	1000
Message Type	4	01xx
Message Data	512	-
Validation Check	8	-
CRC	16	-

Table 3 - Slot Data Message Structure

5.7.3 Acknowledgement Message

The Acknowledgement Message indicates whether or not the prior Slot Data Message was received properly. The format is the same for both the beacon and transponder. All Slot Data Messages shall be acknowledged with a positive or negative response, except for Broadcast messages. The length of the Acknowledgement Message is 40 bits. A summary of the fields within the Acknowledgement Message is given in Table 4 below.

FIELD DEFINITION	NO. BITS	BINARY VALUE

Header Code: Selsyn Flag	 8 8	 01010101 10001101
Data Link Header	4	1000
Message Type	4	1001 (positive ACK) 1000 (negative ACK)
CRC	16	-

Table 4 - Acknowledgement Message Structure

5.7.4 Transponder ID Message

The Transponder ID Message is used by the transponder to notify the beacon that it is present in the communication zone, and to request establishment of a logical link to perform a transaction with the beacon. Battery condition detection status is a vendor option. When detection is implemented, Message Type field shall be coded as shown. Otherwise, Message Type field shall return a 0001 response The length of the Transponder ID Message is 72 bits. A summary of the fields within the Transponder ID Message is given in Table 5 below.

FIELD DEFINITION	NO. BITS	BINARY VALUE
Header Code: Selsyn Flag	 8 8	 01010101 10001101
Transponder Type	4	-
Message Type	4	0000 (low battery) 0001 (battery OK)
Transponder ID	32	-
CRC	16	-

Table 5 - Transponder ID Message Structure

5.7.5 External Transponder ID Message

After establishment of a logical link between the transponder and the beacon, the External Transponder ID Message may used by an attached application layer process to notify the beacon that it has data to send. This message is equivalent to a system interrupt. The length of the External Transponder ID Message is 72 bits. A summary of the fields within the External Transponder ID Message is given in Table 6 below.

FIELD DEFINITION	NO. BITS	BINARY VALUE
Header Code: Selsyn Flag	 8 8	 01010101 10001101
Transponder Type	4	-
Message Type	4	0010
Transponder ID	32	-
CRC	16	-

Table 6 - External Transponder ID Message Structure

5.8 Field Formats and Bit Definitions

5.8.1 Activation Response Parameter

This 2-bit field specifies the probability transponders will use to determine if they will transmit a Transponder ID message in the current frame, or defer activation to a future frame. This field permits the beacon to modulate the level of activity in systems where large numbers of transponders are in the communications zone. The coding of the Activation Response Parameter is shown in Table 7 below.

ACTIVATION PROBABILITY	BINARY VALUE
100%	00
50%	01
25%	10
12.5%	11

Table 7 - Activation Response Parameter Coding

If the transponder chooses to respond in the current frame, the transponder shall interpret the Frame Control field to determine the current frame structure. The transponder shall then randomly select one of the activation slots in which to send the Transponder ID message. If the transponder chooses to defer to a future frame, then no Transponder ID message shall be transmitted in the current frame.

5.8.2 Data Link Header

A 4-bit field reserved for future message control between the transponder and beacon. Field shall be set to a value of binary 1000 to define "no operation".

5.8.3 Frame Control

This 4-bit field identifies the type of beacon protocol and activation control. The coding of the Frame Control is shown in Table 8 below.

FIELD DEFINITION	BIT	BINARY VALUE
Wide-Area Frame Lane-Based Frame	3	1 0
Transponder Activation Inhibited Transponder Activation Enabled	2	1 0
External Activation Inhibited External Activation Enabled	1	1 0
Normal TDMA Framing Extended Variable Framing	0	0 1

Table 8 - Frame Control Coding

5.8.3.1 Frame Type

Bit 3 shall identify which frame structure shall be used for the current frame, as shown in Figure 5-1.

5.8.3.2 Transponder Activation Enabled

If Bit 2=0, transponders entering the communications zone shall make an attempt to gain entry by transmitting an appropriate Transponder ID Message during the Activation Phase. The probability of responding during the Activation Phase, however, shall be governed by the Activation Response Parameter.

5.8.3.3 Transponder Activation Disabled

If Bit 2=1, transponder shall not respond with a Transponder ID Message during the current Activation Phase. The remainder of the FCM shall be still be interpreted and processed, however, and the transponder shall perform any commanded operations.

5.8.3.4 External Activation Enabled

If Bit 1=0, then transponders shall be allowed to respond with an External Transponder ID Message during the current Activation Phase. The probability of responding during the Activation Phase, however, shall be governed by the Activation Response Parameter.

5.8.3.5 External Activation Inhibited

If Bit 1=1, then transponders shall not respond with an External Transponder ID Message during current the Activation Phase. The remainder of the FCM shall be still be interpreted and processed, however, and the transponder shall perform any commanded operations.

5.8.3.6 Normal TDMA Framing

If Bit 0=0, then remaining Frame Control field bits define normal protocol operation as shown in Figure 5-1.

5.8.3.7 Extended Variable Framing

If Bit 0=1, then remaining Frame Control bits must be set as follows: Bit 3=0, Bit 2=0, Bit 1=1. This combination provides a means to permit a beacon to generate an extended variable frame messaging structure. This feature is designed for future expansion. The specific protocol is outside the scope of this standard.

5.8.4 Message Type

This 4-bit field identifies the specific type of VRC message. The coding of the Message Type is shown in Table 9 below.

FIELD DEFINITION	BINARY VALUE
Transponder ID Message with Low Battery Indication	0000
Transponder ID Message with Battery OK Indication	0001
External Transponder ID Message	0010
(Unused)	0011
Normal Slot Data Message	0100
(Unused)	0101
Reserved for Factory Programming Message	0110
Agency Programming Message	0111
Negative Acknowledgement Message	1000
Positive Acknowledgement Message	1001

(Unused)	1010
(Unused)	1011
Frame Control Message	1100
(Unused)	1101
(Unused)	1110
(Unused)	1111

Table 9 - Message Type Coding

5.8.4.1 Reserved Codes

Message Type codes 0110 and 0111 are not user accessible and shall be reserved only for Factory and Agency programming functions.

5.8.5 Message Data

This 512-bit field contains the packet of information that is transferred to or from the transponder. This data could be either a single internal transponder data packet, or external single or multi-packet application data, depending upon bit 4 of the associated Slot Command in the Frame Control Message.

For a Downlink Internal Message only, the first eight bits of the message are a driver interface command field. The coding is given in Table 10.

FIELD DEFINITION	BIT	CODING
Visual Signal Activation	7,6	00 = Visual Signals Off 01 = Activate Green Visual Signal 10 = Activate Red Visual Signal 11 = Activate Yellow Visual Signal
Audio Signal Activation	5,4	00 = Audio Signals Off 01 = Activate Continuous Audio Signal 10 = Activate Intermittent Audio Signal 11 = Not Used
Data Field Indicator	3,2	00 = Data Field Valid 01 = Driver Interface Command Only - Ignore Data Field 10, 11 = Not Used
Reserved	1,0	

Table 10 - Driver Interface Command Coding

5.8.6 Sleep Timeout

This 4-bit field defines the period of time that a transponder shall not attempt activation after a completion of the current transaction with the beacon. The field is coded as binary values from 0000 to 1111. Each value is then multiplied by 2 seconds, i.e., 0-30 seconds.

5.8.7 Slot Command

This 8-bit field identifies the transaction assignment for a specific Message Slot. The bits are coded as follows:

FIELD DEFINITION	BIT	BINARY VALUE
Transmit Message to Beacon Receive Message from Beacon	7	1 0
Acknowledge Message Unacknowledge Message	6	1 0
Last Frame of Transaction Transaction Not Complete	5	1 0
Internal Memory/Application External Memory/Application	4	1 0
Normal Slot Idle Slot Continuous Wave Slot (Undefined)	3,2	00 01 10 11
(Reserved)	1	0
(Reserved)	0	0

Table 11 - Slot Command Coding

5.8.7.1 Bit 7: Transmit/Receive

The transponder shall transmit or receive in the indicated slot depending on the value of this bit field.

5.8.7.2 Bit 6=1: Acknowledged Message

The transponder shall perform the commanded transmission or reception, with acknowledgment. Global ID is not permitted. Positive or negative acknowledgment status shall be passed to the application layer.

If the transponder receives an error-free message during the associated slot, then the transponder shall transmit a positive acknowledgment at the end of the slot. Otherwise, the transponder shall transmit a negative acknowledgment.

If the transponder transmits a message during the associated slot, then the transponder shall expect an acknowledgment from the beacon at the end of the slot. If no acknowledgment is received, then a negative acknowledgment shall be assumed.

5.8.7.3 **Bit 6=0: Unacknowledged Message**

The transponder shall perform the commanded transmission or reception without acknowledgment. No acknowledgment message shall be transmitted or expected. This bit shall be ignored when the beacon uses the Global ID to broadcast messages to all transponders.

5.8.7.4 **Bit 5=1: Last Frame**

The transponder shall attempt to complete the assigned transaction in the current frame, then process the sleep function. If the transaction is completed successfully, the transponder shall initiate the sleep function at the end of the frame, using the sleep timeout value included in the FCM. If the transaction is not completed successfully, the transponder shall not initiate the sleep function at the end of the frame.

For an *addressed receive* slot assignment, the transaction is considered complete if a valid Slot Data Message is received and acknowledged by the transponder in the associated slot.

For any other type of slot assignment, the transaction shall be considered complete after the operation indicated by the Slot Command is carried out by the transponder.

5.8.7.5 **Bit 5=0: Transaction Not Complete**

Transponder shall maintain link activation as additional messages are pending to complete the transaction.

5.8.7.6 **Bit 4=1: Internal Memory/Application**

A single packet message will be sent from or received to the memory within the transponder.

If the single packet is a transponder receive message, then the most significant 8 bits of the 512-bit field are reserved for transponder application layer control purposes. The remaining 504 bits are interpreted as the data field.

If the single packet is a transponder transmit message, then the entire 512 bits shall be constructed using internal transponder memory and ID information.

5.8.7.7 **Bit 4=0: External Memory/Application**

Single packet or multi-packet messages shall be transferred to or from an attached application buffer, depending upon whether the Slot Command indicates receive or transmit. That is, none of the 512 bits in each packet are interpreted by the transponder. The data field is considered to be an end-to-end message between the beacon and the transponder-attached application process.

5.8.7.8 **Bit 3 & 2: Slot Type**

These two bits shall be coded as follows to determine which slot command has been commanded:

FIELD DEFINITION	BINARY VALUE
A normal communication slot, as commanded by bits 7 through 4.	00
The addressed transponder shall remain idle for the associated slot; in this case, bits 7, 6 and 4 shall be ignored.	01
The addressed transponder shall transmit a continuous wave signal for the 560-bit duration of the assigned message slot; in this case, buts 7, 6 and 4 shall be ignored.	10
Currently undefined; when these bits are set to binary value 11, the transponder shall default to idle.	11

Table 12 - Slot Command Type Coding

5.8.8 Transponder ID

A 32-bit binary value which uniquely identifies the link address of each transponder. A mechanism shall be established by an approved authority or organization to allocate unique ID values among manufacturers. Unique ID values shall be in the hexadecimal range between 0000 0001 through FFFF FFFE, inclusive. Remaining addresses are reserved. Four types of transponder IDs are permitted:

5.8.8.1 Global ID

A reserved address with the hexadecimal value of 0000 0000. Every transponder shall decode this value. It shall be used exclusively for broadcast transmission from the beacon to all transponders in the communications zone.

5.8.8.2 Public ID

A permanent, unique 32-bit identifier that is used to determine the link address of each transponder. This identifier shall be programmed once into the unit during factory programming. This identifier shall be used as the Transponder ID only if the Transponder Type field indicates "Public Link Entry". Otherwise, this identifier shall not be used. The Global ID value is not permitted.

5.8.8.3 Random ID

A 32-bit identifier that is chosen at random by the transponder, for the purpose of "Anonymous Link Entry". This identifier shall be chosen only once, upon wake-up, and shall not change value until the transponder exits the logical link (sleeps & re-awakens). This identifier shall be used as the Transponder ID only if the Transponder Type field indicates "Anonymous Link Entry". Otherwise, this identifier shall not be used. The Global ID value is not permitted.

5.8.8.4 Private ID

A permanent, unique 32-bit identifier which may be used exclusively to validate Agency Programming Messages (Message Type Code 0111). This identifier shall be programmed into the unit during factory programming. The Global ID value is not permitted.

5.8.9 Transponder Type

This 4-bit field specifies the type of transponder, what capabilities are available for the transaction, and identifies which transponder ID is used for activation.

FIELD DEFINITION	BIT	BINARY VALUE
Open-Road capable Open-Road or Lane-Based capable	3	1 0
Public Link Entry (use public ID for transponder ID) Anonymous Link Entry (use random ID for transponder ID)	2	0 1
Extended Protocol Capable Internal Read Only Internal Read/Write Internal and External Read/Write	1,0	00 01 10 11

Table 13 - Transponder Type Coding

5.8.9.1 Extended Protocol

Transponder Type field must be set to binary 0000 to signal the beacon of a capability to support an extended protocol. This feature is designed for future expansion. Any specific protocol is outside the scope of this standard.

5.9 Message Processing (Refer to Figure 5-3):

5.9.1 Link Protocol Flow

The VRC communications protocol permits two-way messaging between the beacon and one or more transponders in an application specific communications zone. Messages are separated into one or more data packets of 512 bits each.

Packet communications may be accomplished by, but is not limited to, any of the following means:

- Single packet per vehicle, one to four vehicles simultaneously each frame.
- Multiple packets per vehicle per frame.
- Multiple packets per vehicle in multiple frames.
- Multiple packets between one or more vehicles in multiple frames.

Protocol flowcharts are given in the following figures:

Figure 5-3a: Overall Protocol Flow
Figure 5-3b: Activation Phase
Figure 5-3c: Transaction Phase
Figure 5-3d: Slot Command Processing

5.9.2 Transponder ID Message

Upon first entering the beacon communication zone (after sleep timeout expires) and receiving a valid Frame Control Message (FCM), the transponder shall determine whether or not it is allowed to respond during the Activation Cycle. If the Frame Control field in the FCM indicates "Transponder Activation Enabled", then the transponder is allowed to respond in the Activation Cycle with a Transponder ID Message. In this case, the transponder shall use the Activation Response Parameter provided in the FCM in order to determine the response probability. The response probability shall be used to determine if the transponder will choose to respond in the current frame, or defer to a future frame. If the transponder chooses to defer to a future frame, then no activation message shall be transmitted in the current frame.

However, if the transponder chooses to respond in the current frame, the transponder shall interpret the Frame Control field in order to determine the current frame structure (i.e., how many activation slots). The transponder shall then randomly select one of the activation slots in which to send this message. So long as the Frame Control field indicates "Transponder Activation Mode", the transponder shall repeat this process each frame until link entry is successful, as evidenced by an internal or external message slot assignment that is specifically addressed to the transponder. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be processed properly.

If the Frame Control field indicates "Activation Inhibit", then the transponder shall refrain from responding during the Activation Cycle of the current frame.

5.9.3 External Transponder ID Message

Upon receiving a transmit request from an attached application layer host, the transponder shall determine whether or not it is allowed to respond during the Activation Cycle. If the Frame Control field in the FCM indicates "External Activation Enabled", and if the transponder is currently in the link (i.e., the transponder has been previously assigned a message slot with its own Transponder ID), then the transponder is allowed to respond in the Activation Cycle with an External Transponder ID Message.

In this case, the transponder shall use the Activation Response Parameter provided in the FCM in order to determine the response probability. The response probability shall be used to determine if the transponder will choose to respond in the current frame, or defer to a future frame. If the transponder chooses to defer to a future frame, then no activation message shall be transmitted in the current frame. If the transponder chooses to respond in the current frame, the transponder shall interpret the Frame Control field in order to determine the current frame structure (i.e., how many activation slots). The transponder shall then randomly select one of the activation slots in which to send this message. So long as the Frame Control field indicates "External Activation Enabled", and the transponder remains in the link, the transponder shall repeat this process each frame until host link access is provided, as evidenced by an external message slot assignment. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be properly processed.

If the Frame Control field indicates "External Activation Disabled", then the transponder shall refrain from responding during the Activation Cycle of the current frame.

5.9.4 Downlink Internal Message Slot

5.9.4.1 Data Storage

A message from the beacon to the transponder internal 512 bit message buffer. If the message was received without error then a positive acknowledgement shall be sent to the beacon if so commanded. If the data was received in error, the information shall be discarded and a negative acknowledgement sent to the beacon, if so commanded.

If the data field valid field in the driver interface command field indicates that the message data is valid, then the 256 least significant bits of the message shall be stored in the general-use portion of the transponder's internal memory. If the data field valid field in the driver interface command field indicates that the message data is not valid, the message data shall be discarded. However, the driver interface command shall be executed in all cases of a valid message reception.

5.9.4.1 Driver Interface Commands

Upon receipt of a valid Downlink Internal Message , the transponder shall activate the appropriate signals immediately. These signals shall be activated independently of the sleep function. Furthermore, the specified signal command shall override any previous signal command that is still active.

5.9.5 Downlink External Message Slot

A message from the beacon to a 512 bit buffer not located in the transponder. If the message was received without error then a positive acknowledgement shall be sent to the beacon if so commanded. If the data was received in error, the information shall be discarded and a negative acknowledgement sent to the beacon, if so commanded.

5.9.6 Uplink Acknowledgement Message

During an assigned message slot in which thetransponder is scheduled to receive an addressed Slot Data Message, the transponder shall transmit an Acknowledgment Message with either a positive or negative indication. *Note that, during non-addressed message slots, acknowledgments are not expected, and should be ignored entirely.*

5.9.7 Uplink Internal Message Slot

A scheduled transmission in an assigned message slot from the transponder to the beacon. The entire 512-bit field shall constructed using internal transponder memory and ID information. The least significant 256 bits of this field shall be copied directly from the general-use memory. The lower 192 bits of the most significant 256 bits shall be copied directly from the agency memory. The most significant 64 bits shall be used for transponder identification. Of these 64 bits, the most significant 32 bits shall be set equal to the Transponder ID (which could be either the Public ID or the Random ID). The lower 32 bits of this 64-bit field shall be set to zero (the Private ID shall never be transmitted). Table 14 defines the bit positions of each field in the uplink message.

FIELD DEFINITION	FIELD SIZE (BITS)	BIT NUMBER
Public ID	32	480-511
All Zeros	32	448-479
Agency Memory Contents	192	256-447
General-Use Memory Contents	256	0-255

Table 14 - Uplink Message Contents

5.9.8 Uplink External Message Slot

A scheduled transmission in an assigned message slot from the transponder to the beacon. The transponder shall obtain the message packet from an external 512 bit buffer (application layer) and build the Slot Data Message.

5.9.9 Downlink Acknowledgement Message

During an assigned message slot in which the transponder is scheduled to transmit an addressed Slot Data Message, the beacon shall transmit an Acknowledgment Message with either a positive or negative indication. *Note that, during non-addressed message slots, acknowledgments are not expected, and should be ignored entirely.*

5.9.10 Agency Programming Message Processing

All Agency Programming message types shall be validated & checked in the same manner as other Slot Data Messages, except that the Validation Check field shall also depend upon the 32-bit Private ID, in addition to the 64-bit Validation Seed and the Message Data field. To accomplish this Validation Check field calculation, the Private ID shall be combined with the Message Data field, via an exclusive-or operation, prior to clocking the Message Data field through the LSG authentication algorithm. The Private ID shall be aligned with the first 32 bits of the least-significant 256 bits of the Message Data field.

If the transponder receives a validated, error free Agency Programming message, it shall extract the first 192 bits of the least significant 256 bits of the Message Data field, and write this data into the Agency Memory.

8 Other Requirements

8.1 Safe Operating Radiation Levels

VRC equipment shall not generate radiation levels greater than the power density limits specified in ANSI specification C95.1 - 1982. The VRC equipment shall not degrade beyond the specified limits throughout its operating life.